

Innovative Solutions for the Control of Structures Response to Dynamic Action

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Abstract

The reduction of the effects of the dynamic action (earthquakes, wind, shocks and vibrations) on structures (buildings, equipment and pipe network) confronts difficult problems regarding their large size and weight as well as their high seismic acceleration or displacement. This paper proposes two alternatives to this critical problem.

Solution 1 aims at a new seismic isolation system for buildings. The technological connections are achieved with special supports which allow a relatively high movement between the isolated and non-isolated buildings.

Solution 2 aims at minimizing the dynamic structures response by relative deflection control and dissipation of a large amount of energy.

The new solutions must be designed to be applied to new structures and to increase the degree of resistance to existing structures.

The new devices, called "SERB-devices" can overtake large static loads over which dynamic loads may overlap and be damped. The devices allow "cutting-off" the dynamic action coming from the environment or generated from inside structures as well as the overtaking of shocks and vibrations generated by the systems to protect the environment.

Keywords

Buildings Isolation; Damping Devices; Isolation Devices; Vibrations and Seismic Movement; Base Isolation Systems; Earthquake Protection; Pipeline and Equipment Supports

Introduction

Protection of structures (building, equipment and pipeline networks) is required by safety, economic and functionality, before, during and after a dynamic action.

A dynamic action is defined through repeated

oscillatory motions that put structures in forced vibration motion. According to the ratio between the dynamic characteristics of structures (it's dominant eigen vibrating period) and kinematic characteristics of dynamic action (dominant periods of repeated oscillations), the dynamic response of the structures to the dynamic action may be several times larger or smaller than the direct dynamic action.

The effect of dynamic action on structures is dependent on both the intensity of the dynamic action and the response of the dynamic systems of structure. The excitation may be transferred to the dynamic system, a quantity of energy per oscillation cycle equal or smaller than the energy corresponding to one oscillation cycle, function of the harmonization or non-harmonization of the system eigen motion with the dynamic action.

Innovative design solutions to structure's protection to dynamic action are those that make their dynamic response to dynamic action very small (usually less than direct dynamic action) while keeping their functionality and/or integrity.

In order to reveal how the total dynamic loading (action + response) of a system may be reduced, the authors have analysed the behaviour of the dynamic response on a SDOF (single degree of freedom) oscillating system in time and frequency domain, subjected to a harmonic dynamic action.

The transferred energy can be injected into the system and, in some cases, it leads to important amplifications of the system response harmful to safety. The amplification of the structures response depends on both the damping capacity and the degree of

harmonization (measured as a ratio between the system eigen period and the excitation repetition period) of the system with the excitation.

This paper is also a presentation of in-time and frequency of the dynamic behaviour of a system on a model with a degree of freedom and a setting-up of its sizing criteria to withstand dynamic actions (earthquakes).

Mathematical Model for the Systems Response to Dynamic Actions

In-Time Analysis

In order to examine how the total dynamic loading (action + response) may be reduced to a system, in-time analyses of the response on a SDOF oscillating system, subjected to a harmonic dynamic action, are presented. Consider a SDOF with a mass m , damping c (damping force is proportional to the vibration velocity) and stiffness k (elastic force is proportional to the relative displacement). The oscillating system is subjected to an oscillating movement of the support, marked as $u_s(t)$, that, in the analyses, is approximated with an harmonic T_s period movement, with the form:

$$u_s(t) = A \sin \Omega t, \quad \Omega = \frac{2\pi}{T_s} \quad (1)$$

The motion equations of the oscillating system, written in terms of relative displacement, $x(t)$ and the total displacement $y(t)$, respectively, are:

$$\ddot{x}(t) + 2\beta\omega\dot{x}(t) + \omega^2x(t) = A \sin \Omega t \quad (2a)$$

$$\ddot{y}(t) + 2\beta\omega\dot{y}(t) + \omega^2y(t) = \omega^2 A \sin \Omega t + 2\beta\omega A \Omega \cos \Omega t \quad (2b)$$

With the initial conditions: $x(0) = 0$, $\dot{x}(0) = -v_0$; $y(0) = 0$, $\dot{y}(0) = 0$ respectively

Where v_0 is the relative velocity in the initial moment that is equal and opposite (in direction) with the support velocity in the initial moment $t = 0$, (usually the initial velocity is different than zero). Herein below there is an analysis of the movement of an oscillating system by means of the motion equation (2b) because initial conditions are known. The oscillating system is analysed for 5 vibration periods: $T = 0.707$ s, 0.90 s, 1.00 s, 1.10 s and 1.414 s and damping $\beta = 5\%$. This oscillating periods correspond to 5 SDOF behaviour cases. The dynamic action is given by a harmonic wave of amplitude $A = 0.225$ m and repetition period $T_s = 1.0$ s, for all the analysed cases.

The kinetic – E_c , elastic – W_p and total energy – E_T related to the mass unit of the oscillating system expressed in function of absolute velocity and relative displacement, are expressed by the relations:

$$E_c = \frac{1}{2} \dot{y}^2, \quad W_p = \frac{1}{2} \omega^2 x^2, \\ E_T = E_c + W_p = \frac{1}{2} (\dot{y}^2 + \omega^2 x^2), \text{ respectively} \quad (4)$$

Fig. 1 – 5 illustrate the in-time variation of the total and relative displacement of the oscillating system and of the excitation (support motion) for the 5 cases analysed. Fig. 6 –11 illustrate the in-time variation of the amplitude of the kinetic, elastic and total energy accumulated in the oscillating system related to the amplitude of the excitation energy (to the oscillating system mass unit) for $\beta = 5\%$. The results point out the fact that flexible systems accumulate more elastic energy and stiff and half-stiff systems accumulate more kinetic energy so that such systems have the physical capacity to overtake the kinetic energy with controlled stress or strength. Fig. 11 makes a comparison between the total energy accumulated by an oscillating system in resonance regime with the excitation, for damping of 5%, 10% and 20%.

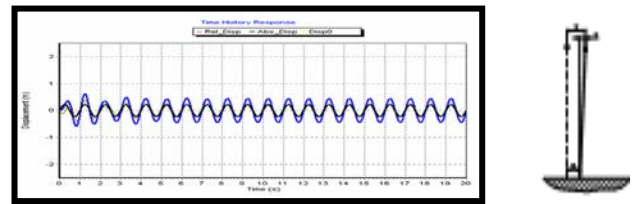


FIG. 1 CASE A – SEMI – RIGID SYSTEM. $T = 0.707$ s, $T \ll T_s$, $T_s = 1.0$ s, $\varphi > 0^\circ$, $\beta = 5\%$

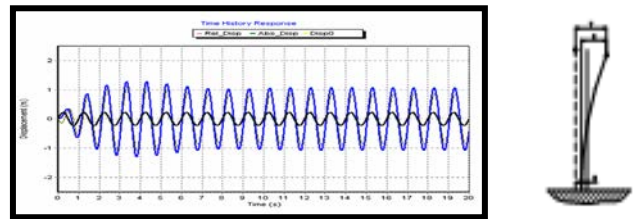


FIG. 2 CASE B – SYSTEM IN PRE-REZONANCE. $T = 0.9$ s, $T < T_s$, $T_s = 1.0$ s, $\varphi < 90^\circ$, $\beta = 5\%$

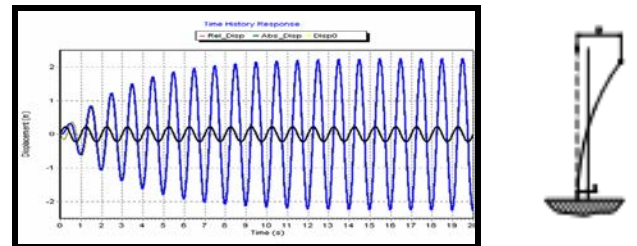


FIG. 3 CASE C – SYSTEM IN REZONANCE WITH EXCITATION. $T = 1.0$ s, $T_s = 1.0$ s, $\varphi = 90^\circ$, $\beta = 5\%$

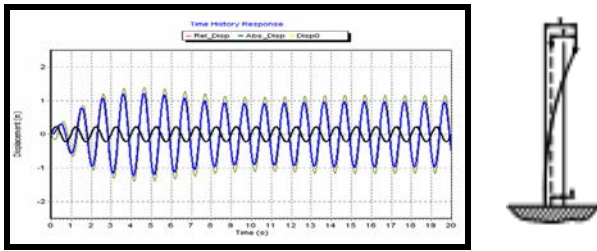


FIG. 4 CASE D – SYSTEM IN POSTREZONANCE. $T = 1.1s$, $T > T_s$,

$$T_s = 1.0s, \varphi > 90^\circ, \beta = 5\%$$

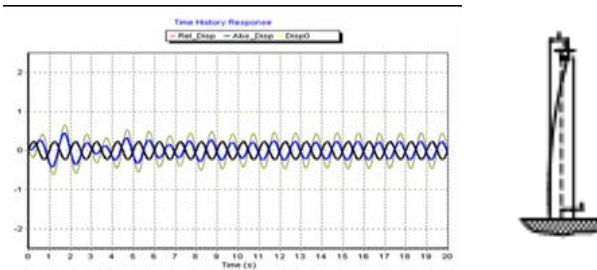


FIG. 5 CASE E. SYSTEM ISOLATION $T = 1.41s$, $T \gg T_s$,

$$T_s = 1.0s, \varphi < 180^\circ, \beta = 5\%$$

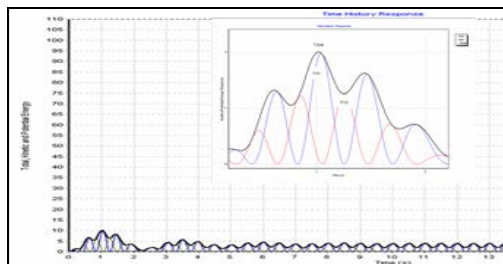


FIG. 6 CASE A. THE KINETIC AND ELASTIC TIME HISTORY.

$$T = 0.707s, T_s = 1.0s, \beta = 5\%$$

In case A, the oscillating system's kinetic energy is greater than its elastic energy which decreases with the increase of the system stiffness and becomes zero at a completely stiff system. The maximum kinetic energy of the system is practically equal to the maximum energy of the source. The system is not oscillating and is not accumulating the excitation's energy.

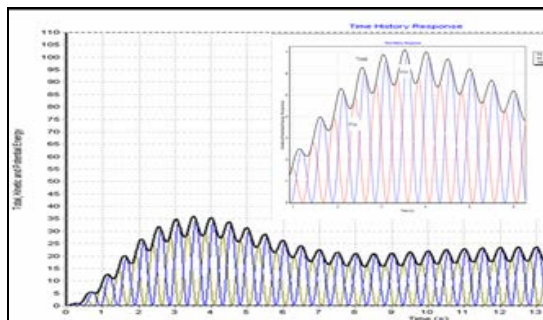


FIG. 7 CASE B E_c AND W_p TIME HISTORY $T = 0.9S$.

$$T_s = 1.0S, B = 5\%$$

In case B, the oscillating system's elastic energy increases but it remains smaller than the kinetic energy. The system may accumulate a limited quantity of energy from the excitation. The maximum energy accumulated by the oscillating system is also dependent on the system capacity of dissipation when it comes near to resonance.

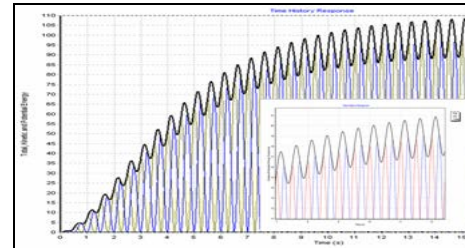


FIG. 8 CASE C. THE E_c AND W_p TIME HISTORY $T = 1S$.

$$T_s = 1.0S, \beta = 5\%$$

In case C, the oscillating system's kinetic energy is equal to the elastic energy. The oscillating system may accumulate a large quantity of energy, and its maximum value is limited only by the dissipation capacity of the oscillating system. The only solution to limit the total energy of the oscillating system in this vibration regime is to increase the system damping.

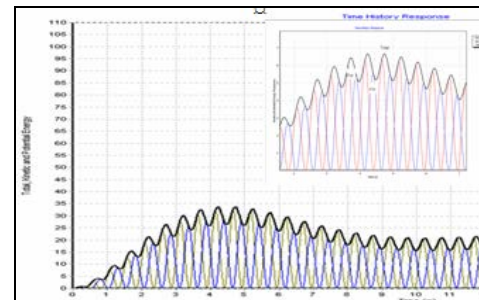


FIG. 9 CASE D. THE E_c AND W_p TIME HISTORY $T = 1.1S$.

$$T_s = 1.0S, \beta = 5\%$$

In case D, the oscillating system's elastic energy is greater than the kinetic energy. The oscillating system may accumulate a limited quantity of energy which is also dependent on the system damping capacity. The greater the oscillating system flexibility is, the smaller the energy transferred from the excitation to the oscillating system is and as well, the oscillating system is capable to accumulate energy since the excitation is non-harmonized versus the oscillating system eigen movement.

With case E, the system's elastic energy is greater than its kinetic energy decreasing with the increase of the system flexibility, both of them becoming zero at the systems with very high flexibility. The system cannot accumulate energy from excitation and practically, the

excitation cannot make the oscillating system vibrate. For example, buildings seismically isolated or buildings with controlled degradations (plastic hinges), are away from the resonance area, (see case E of behaviour).

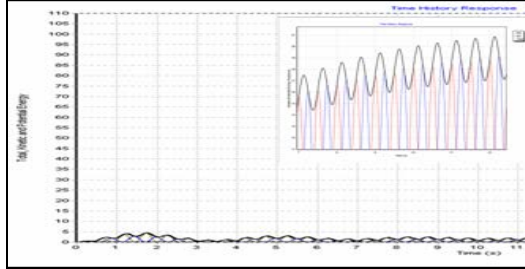


FIG. 10 CASE E. THE E_c AND W_p TIME HISTORY $T = 1.414S$.

$T_s = 1.0S$, $\beta = 5\%$

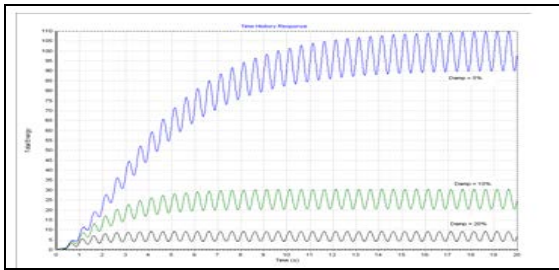


FIG. 11 THE SYSTEM AND EXCITATION TOTAL TIME HISTORY ENERGY IN RESONANCE REGIME FOR 5%, 10% AND 20% DAMPING. $T=T_s=1.0S$

Analysis on the maximum energy accumulated by an oscillating system in resonance with excitation for various damping (Fig. 11), results in that its damping has a great effect on the decrease of the oscillating system's response.

Considering that the dynamic excitation is usually inclusive of several harmonic components whose responses need to be attenuated as much as possible, the safe solution to decrease the total dynamic movement on the systems is to build systems having a great damping capacity, including small distortions, without damaging the structural elements.

Analysis in frequency

The amplitudes of the kinetic and elastic energies, specific to the mass of the oscillating system versus the source energy amplitude E_s , are:

$$|E_c| = \frac{(r^2 + 4\beta^2)r^2}{(r^2 - 1)^2 + 4\beta^2 r^2} \cdot |E_s|$$

$$|W_p| = \frac{r^2}{(r^2 - 1)^2 + 4\beta^2 r^2} \cdot |E_s| \quad (5)$$

with $r = \frac{\omega}{\Omega}$

For an oscillating system's response to dynamic loads with smaller or equal amplifications compared to the static loads with the same intensity (without amplification), it is necessary that the amplitude of the kinetic and elastic energy, accumulated in the oscillating system, should be smaller or equal to the excitation energy: $|E_c| \leq |E_s|$, $|W_p| \leq |E_s|$.

For the kinetic energy, the condition is: $T \geq \sqrt{2} \cdot T_s$ (6)

Irrespective of the oscillating system damping.

The condition that the maximum elastic amplitude energy of the oscillating system is smaller or equal compared to the maximum amplitude energy of the source per oscillating cycle is dependent on the oscillating system damping and corresponds to an oscillating system vibration period greater than $\sqrt{2}T_s$. For a critical damping ratio smaller than $\beta = 0.30$ it results in that for the dynamic protection solution to be efficient, it is necessary that the eigen vibration period of the system should be practically twice bigger than the dominant period of the excitation in site, $T > 2T_s$. For instance, in case of Bucharest area, it is necessary that the eigen vibration period of the building seismically isolated should be greater than 3.2 s, because the corner period in the ground response spectrum is $T_c = 1.6$ s (dominant period from seismic movement).

Figs. 12 – 13 illustrate the variation of the kinetic and elastic energy amplitude of an oscillating system for $\beta = 5\%$ and $\beta = 20\%$.

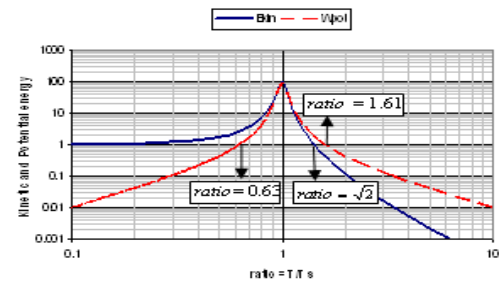


FIG. 12 THE E_c AND W_p AMPLITUDE ENERGY RELATED TO T/T_s , $\beta = 5\%$

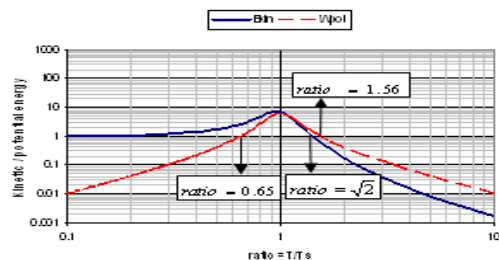


FIG. 13 THE E_c AND W_p AMPLITUDE ENERGY RELATED TO EXCITATION ONES. $\beta = 20\%$

According to the analysis on the diagrams, it can be observed that the most efficient solution to reduce the total energy of a system subjected to dynamic actions is to make an elastic connection with large damping at the level of the support structure.

The kinetic and elastic energy accumulated in the system from the source is about 100 times greater for $\beta = 5\%$ than the energy of the excitation for resonance $T = T_s$ and only about 10 times greater for $\beta = 20\%$ than the energy of excitation.

If system eigen vibration period T is 3 times greater than the excitation repetition period T_s , then the potential energy accumulated in the oscillating system will be 10 times smaller than the energy on one oscillating cycle.

For a better understanding of the energy transfer phenomenon from the excitation to the oscillating system, herein below the presented analysis of the velocity of the energy transfer from the ground to the building is made by means of the evaluation of the transfer of power from the excitation to the oscillating system.

The amplitude of the dissipated power (P_d) of the oscillating system and of the power transferred (P_{er}) from the excitation to the oscillating system related to the system unit mass, is:

$$|P_d| = \frac{4\beta\omega\Omega^3}{(\omega^2 - \Omega^2)^2 + 4\beta^2\omega^2\Omega^2} |P_s| \quad , \quad \text{respectively}$$

$$|P_e| = \sqrt{\frac{\omega^2 + 4\beta^2\Omega^2}{(\omega^2 - \Omega^2)^2 + 4\beta^2\omega^2\Omega^2}} \omega |P_s| \quad (7)$$

Fig. 14 and 15 show the amplitude variation of the P_{er} from the excitation to the oscillating system and the amplitude of the P_d by the oscillating system for a mass unit of the oscillating system function of the ratio between the oscillating system period and the period of the excitation for 5% and 20% of the critical damping.

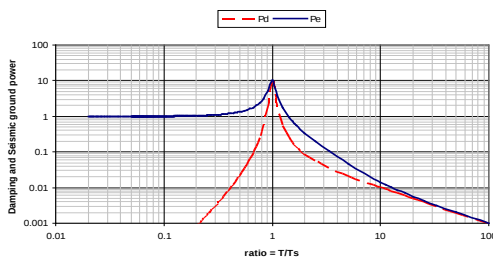


FIG. 14 THE P_{ER} AMPLITUDE TO THE OSCILLATING SYSTEM AND P_D POWER AMPLITUDE IN THE OSCILLATING SYSTEM $\beta=5\%$, T/T_1

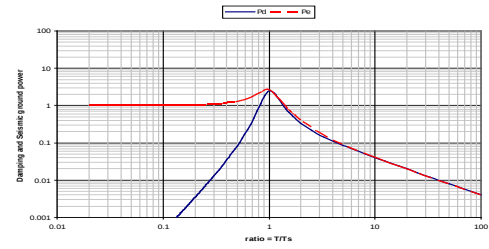


FIG. 15 THE P_{ER} AND P_D TO THE OSCILLATING SYSTEM AMPLITUDE IN THE OSCILLATING SYSTEM.

$\beta=20\%$, T/T_1

Based on the analysis on the diagrams, it can be seen that the amplitude of the power transferred from the excitation source to the oscillating system is practically equal to the amplitude of the excitation power for the oscillating system vibration periods smaller than $0.4T_s$. For example, the very good behaviour of block of flats made of prefabricated elements in Bucharest during the earthquake in 1977 is a confirmation of the phenomenon on a real case. For vibration periods greater than $0.4T_s$, the oscillating system starts to accumulate energy from the transferred power and the amplitude of the dissipated power reaches 1% of the excitation power amplitude.

The interaction forces which act upon the oscillating system (elastic with damping), performing thus the energy transfer from the excitation to the oscillating system are determined in function of the equivalent amplitude excitation force, $F_x = \Omega^2 U_0$ for a mass unit oscillating system.

$$|F_e| = \frac{\omega^2}{\sqrt{(\omega^2 - \Omega^2)^2 + 4\beta^2\omega^2\Omega^2}} \cdot |F_x|$$

$$|F_d| = \frac{2\beta\omega\Omega}{\sqrt{(\omega^2 - \Omega^2)^2 + 4\beta^2\omega^2\Omega^2}} \cdot |F_x|$$

$$|F_s| = \sqrt{\frac{\omega^2 + 4\beta^2\Omega^2}{(\omega^2 - \Omega^2)^2 + 4\beta^2\omega^2\Omega^2}} \cdot \omega \cdot |F_x| \quad (8)$$

Figs. 16 and 17 show the amplitude variation of the damping force F_d , elastic force F_e and total force F_s versus the amplitude of the inertia force associated with the excitation, F_x related to the mass unit of the oscillating system, function of the ratio between the oscillating system vibration period and the excitation period for 5% and 20% critical damping.

The analysis of the diagrams shows that for oscillating system periods smaller than the excitation dominant period, the elastic force F_e governs the interaction force. The damping force becoming more important at resonance and post-resonance, are dominant when

the oscillating system passes to the isolation range ($T \gg 2T_s$), a reason for which the damping must be limited to 30%.

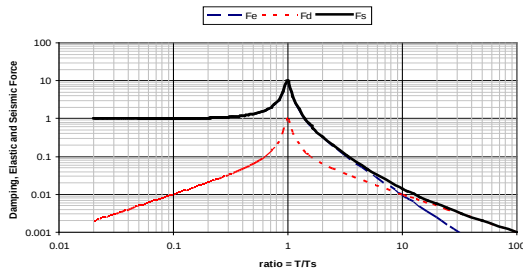


FIG. 16 THE F_E , F_D AND F_S . $\beta=5\%$, T/T_1

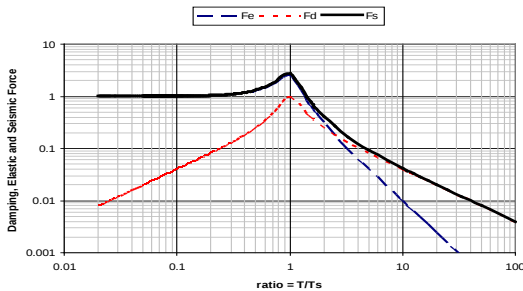


FIG. 17 THE F_E , F_D AND F_S . $\beta=20\%$

Technical Solutions to Reduce the Systems Response to Dynamic Actions

Theoretic aspects

Based on the in-time and in-frequencies analyses of a SDOF response, in order to reduce the dynamic response of a system to a repeated dynamic action, the following effects must be performed:

1. The energy transfer in an oscillation cycle from the dynamic action to the oscillating system has to be minimal;
2. The amount of energy accumulated in the oscillating system has to be minimal;
3. The amount of energy dissipated in the oscillating system on a vibrating cycle has to be maximal.

These issues cannot be accomplished simultaneously.

According to the ratio between the oscillating system's own vibrating period T and the excitation repetition period, T_s , several specific situations can be met. In all these situations, there should be borne in mind that the power transfer from the dynamic action to the oscillating system mass is accomplished both by elastic and damping forces and the energy dissipation of the oscillating system is accomplished only by damping forces. For this reason between the two types of forces,

there must be an optimum ratio in order to get a minimum response of the system to the repeated dynamic action.

Possible specific situations in an oscillating system defined by its vibrating period T to the repeated dynamic action period T_s are:

System flexible to the dynamic action $T \gg T_s$

In this case the oscillating system is in *isolation state* when practically the dynamic action applied to the base is not transferred to the system mass. In practical design cases, $T > 3 T_s$ should be in consideration because the evaluation of T and T_s are affected by calculation and measurement errors. We call this area the "input isolation area."

System rigid to dynamic action $T \ll T_s$.

In this case, the oscillating system is in *transport state* and does not realize a relative deformation of the system.

In practical design cases, $T \leq T_s/3$ is recommended including the reason explained in paragraph 1. For $T = T_s/3$ the elastic energy accumulated in the oscillatory system is about 10 times less than the energy of excitation on a cycle of oscillation and kinetic energy of the oscillating system is practically equal to the energy associated with one oscillation cycle of the excitation. This area of the spectrum input is called "transport area".

Resonance system to the dynamic action $T \approx T_s$

In this case the system is located in *resonance state* when the transfer of energy from the excitation to the oscillating system is maximum. The system response increases leading also to the growth of energy dissipation.

Maximum amplification occurs for $T = T_s$ but important amplifications occur for periods of vibrations of the system in the neighbourhood of T_s . In practical cases of design, the resonance area is considered: $T_s / \sqrt{2} \leq T \leq \sqrt{2} \cdot T_s$.

Transient system states near resonance

The oscillating system may be found in transient states in which an important change of the system response occurs with the variation of its period of vibration. These *transient states* are: *transport-resonance* and *resonance – isolation*.

Oscillating systems in these states change their response in "avalanche" depending on the modification of the vibration period. Changing the vibration period of an oscillatory system occurs when the state of stress and strength from the oscillating system components exceed the limit of elastic domain.

The pre-resonance area

The system is elastic and gains energy from excitability in avalanche regime. Accumulation of energy in oscillatory system leads to an increase in dynamic response. If in the system degradations appear in the component materials at joints, the oscillating system is unstable and may appear high amplifications of the dynamic response to destroy it, because it reduces the capacity of resistance of the system materials at the same time with the increase in the response of the system to dynamics actions.

The post-resonance area

The system is elastic, but takes over from excitations less amount of energy than that of an oscillation cycle. This energy accumulates in a smaller amount in the oscillating system. If there are overloads of component materials leading to an increase of the vibration period of the oscillating system T and consequently its dynamic response is reduced.

All high buildings affected by fast earthquakes $T_c < 0.5s$ are situated in the post – resonance or isolation area and through degradation (if these phenomena appears) their seismic response is reduced significantly. For this reason, the solution of accepted controlled degradations for buildings affected by fast earthquakes $T_c < 0.5$ sec. is a good solution in terms of construction safety and human lives saving.

Applying the same seismic design solutions to constructions in areas affected by slow earthquakes $T_c > 0.5s$ (as the case in parts of Romania, where intermediate Vrancea earthquakes occur) is a scientific and technical legitimated error in the seismic design codes (Code P100 in Romania).

Practical aspects

Innovative solution to reduce the dynamic response of a system refers to the control of dynamic behaviour of structures by means of special elastic mechanical damping devices.

Conceptually and practically two types of devices

have been developed, for the control, limitation and damping of the dynamic response of a system:

- Devices for dissipation of energy and control over deformities of the system subjected to a dynamic action;
- Devices for the isolation of the system towards the dynamic action.

SITON and SIGMA SS have been developing and applying the new method and technology to reduce shocks, vibrations and seismic movements in buildings, equipment and pipe networks for more than 20 years. The first industrial application was the isolation of forging hammers (36 tons each) against shocks, vibrations and earthquake, located in IUS SA Brasov, in 2003 (FIG. 18 – 19) and 2004 (FIG. 20). The operation of the isolation system in IUS-Brasov without repairs for a period of 10 years represents a guarantee certificate for the new technology developed by SIGMA SS - SITON.

Among the performances of the system, is worth mentioning: 98% isolation ratios of the system; the suppression of the vibration in 1.5 oscillation cycles; the removal of the "jumping" effect; the reduction of the vibration amplitude in the near-by houses located at about 150 m from the production hall by more than 800 times, i.e. from 56 mm/sec - with the old foundation isolation solution-to 0.069 mm/sec- with SERB new foundation solution.

The isolating devices designed and constructed in Romania, have not modified their elasticity and damping characteristics although the operation conditions are very severe (110 blows/minute generated by a 450 kg forging hammer developing an energy of 36 KJ/blow).

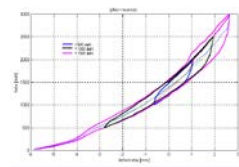


FIG. 18 IUS 2003. FOUNDATION. SERB-194-3C AND HYSTERETIC CURVES

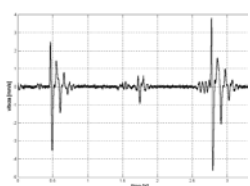
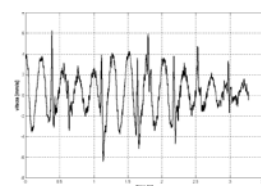


FIG. 19 IUS 2003. WAVE SHAPE RECORDED ON THE FOUNDATION IN THE OLD AND NEW SOLUTION

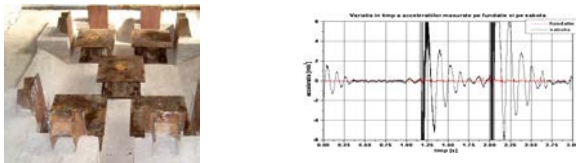


FIG. 20 IUS 2004. CM1250 FOUNDATION AS PER SERB-375C AND TIME HISTORY OF THE ACCELERATION ON FOUNDATION VAT AND BED PLAT

During 2006 and 2009 in ROMAG-PROD, the isolation of 10 electric and I&C cabinets, associated with the H₂S compressors by SERB device against shocks, vibrations and earthquakes was implemented, (FIG. 21).



FIG. 21 ROMAG-PROD. CABINET ISOLATION SERB DEVICE - 2006-209 AND CABINET WITH SERB DEVICE

In addition, in 2006 the most important application of SERB solution was made, namely the first non-traditional seismic strengthening of a building in Romania where the seismic loads are overtaken and damped by SERB mechanical devices installed into a network of telescopic braces with a controlled elasticity and damping.

The building strengthened, extended and refurbished, is Ward B of NAVROM BUSINESS CENTRE – Galati, a 6-story building made of reinforced concrete frames.

The building has been damaged by earthquakes in 1977, 1986 and 1990 (FIG. 22-23), and after strengthening and rehabilitation, it is meant to be used as a hotel and restaurant.



FIG. 22 NAVROM WARD B. HYSTERETIC CHARACTERISTIC AND TELESCOPIC BRACING ANCHORED TO COLUMNS



FIG. 23 NAVROM WARD B. DAMAGE OF REINFORCED STRUCTURES AND STRENGTHENED STRUCTURE



FIG. 24 SERB-SITON CT140/10 SUPPORT, INSTALLATION ON COLD-BOX AND HYSTERESIS DIAGRAM

In 2011-2012, SITON and SIGMA SS have developed isolation solutions to noise, shocks, vibrations and earthquakes for the Integrated Centre for Advanced Laser Technologies – CETAL Bucharest-Magurele-Romania. The isolation was made for: Dynamic High Precision Measurements Lab, Shaker Platform and Clean Room Characterization, Laboratory Standard Frequencies – Lengths.

The developed isolation system provides a high reduction of noises and vibrations for the entire range of frequencies that affect the site. In normal operating conditions, the amplitude of the vibrations is less than 3×10^{-6} m/s. During earthquakes, the isolation system ensures the integrity and reliability of constructions and insulated equipment.

In FIG. 25 the mechanical isolation and control devices of relative displacements used in CETAL are presented.



FIG. 25 MECHANICAL ISOLATION AND CONTROL DEVICES OF RELATIVE DISPLACEMENTS USED IN CETAL

Conclusion

The paper points out the fact that a system may accumulate energy several times greater or smaller than the excitation energy associated with one oscillation cycle, function of the manner in which its eigen vibration periods are situated towards the dominant periods of the excitation.

The results of the analysis show that an efficient solution to reduce the dynamic response of a system is to increase the damping capacity of the system structural elements in the linear loading range.

Moreover, the results show that the most efficient method to improve the system behaviour to withstand dynamic actions is to isolate it.

Further innovative solutions developed through applications have been presented by a group of companies under the auspices of SITON to protect structures against repeated dynamic actions.

According to the experimental data obtained from the industrial applications, the SERB solution used to provide the control, limit and damp of shocks, vibrations and dynamic action at structures, equipment and pipe networks, is ranked as the most efficient solution.

For the applications of innovative solutions to protect buildings, systems and equipment against repeated dynamic actions and/or violent earthquakes, under the auspices of SITON the followings are carried out:

- SERB-SITON solution to isolate the equipment to IUS – Brasov shows superior results compared to those in literature until now. The average degree of isolation against shocks & vibrations is about 97% for certain cases.
- Strengthening and expanding the building in reinforced concrete frames from NAVROM Galati using the SERB devices for the control of relative level displacements and seismic energy dissipation could be achieved in terms of safety and stability even if the alluvial type foundation did not allow the rehabilitation of the building using classical solutions.
- Seismic isolation of ROMAG-PROD electric and I&C cabinets, associated with the H₂S compressors by SERB devices against shocks, vibrations and earthquakes enabled the raising of their safety level in functioning, during an earthquake and minimization of expenditures for the seismic qualification of the lockers.
- Seismic qualification of Cold – Box in the pilot experimental installation for radioactive material separation at ICSI Ramnicu-Valcea was performed without any intervention on the equipment when using SERB supports with high damping and nonlinear force-displacements characteristics.
- The SERB solution for isolation to noise, shock, vibrations and seismic movement in

CETAL allows meeting the requirements imposed by high precision laser equipment and the process equipment generating noise and vibration in the same building with minimal cost and without additional requirements on the location and the whole building.

- Innovative solutions to increase the safety of the structures, equipment and pipeline networks to dynamic actions including violent earthquakes developed under the auspices of SITON is a safe and inexpensive alternative whose performance has been demonstrated by a series of performances conducted.

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